# MAGNETIC RECORDING MEDIUM, METHOD OF MANUFACTURING THE SAME MEDIUM AND MAGNETIC DISC DRIVE

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to a magnetic recording medium applied to a hard disc drive and a method of manufacturing the same medium.

In recent years, reduction in size and enlargement of capacity are essential requirements for a hard disc drive which plays the concentrated role of an information storage apparatus. These requirements can be realized by enhancing the recording density of a magnetic disc medium. In order to increase the recording density, it is requested to realize reduction in thickness of a magnetic film, improvement in resolution, high coercive force and low noise.

### Description of the Related Art

As the recording density of a magnetic disc medium becomes high, an area of one bit on the medium is reduced. In such background, it is required, for acquisition of an output, to make thinner the magnetic layer corresponding to reduction in size of bit. Thereby, a semi-circular magnetic field can be assured and thereby leakage magnetic field generated from the magnetization area of one bit can be obtained. Moreover, since it is also required to narrower the bit interval,

improvement in the magnetic domain structure in the magnetization transition area, scale-down of crystal grain corresponding to reduction in thickness and noise reduction by reduction in magnetic mutual operations among the particles or the like are necessary.

As a magnetic layer of medium, a CoCr group alloy polycrystalline film formed of three or more elements has been used as a material of magnetic layer. In the existing medium, Cr included in the magnetic grains of magnetic layer is segregated into the crystal grain boundary and this grain boundary is non-magnetized to reduce mutual operation among the particles. In the related art, in order to promote this segregation, adding coefficient of Cr to alloy is increased, Ta or the like is added and a substrate is also heated during the film forming process.

As explained above, while a means for segregating Cr included in the magnetic grains into the crystal grain boundary and non-magnetizing this gain boundary region is introduced, it is essential to use the CoCr group alloy magnetic material as a material of magnetic layer. However, when reduction in thickness of magnetic layer and scale-down of crystal grains are promoted, a volume of individual magnetic gains is reduced, thermal disturbance is finally generated to result in the super-normal magnetization and the magnetic recording condition can no longer be maintained. In order to

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reduce the volume of individual magnetic grains as much as possible to a small amount, it is the best means to use a magnetic material having higher anisotropic constant Ku. In the Co-based magnetic material, a value of Ku is lowered as much as about one digit by adding Cr to the discrete element of Co. Therefore, use of the CoCr group alloy will make it very difficult to maintain the value of Ku. Moreover, the discrete element of Co will brings about a problem that corrosion proof characteristic is deteriorated.

An object of the present invention is to provide a magnetic recording medium having higher recording density. Moreover, another object of the present invention is to realize reduction in thickness of a magnetic film of a magnetic recording medium. Moreover, the other object of the present invention is to reduce noise of the magnetic recording medium itself. Disclosure of the Invention

In the present invention, unlike the CoCr group alloy used as a material of a magnetic layer, a Co-based alloy, where a non-magnetic element different from Cr is added to the Co discrete element, is used as a material of the magnetic layer. According to the present invention, reduction of the value of Ku due to the formation of alloy is controlled and thereby a problem in reduction of thickness of magnetic layer in a magnetic recording medium can be solved.

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However, when a Co-based alloy not including Cr is used as a material of magnetic layer, Cr included in the magnetic grains is segregated into the crystal grain boundary and the grain boundary region can no longer be non-magnetized.    Therefore, in the present invention, a Cr-based non-magnetic material is used as an underlayer. According to the present invention, the grain boundary region can be non-magnetized by segregating Cr to the crystal grain boundary from the underlayer.    In more practical, diffusion of Cr into the crystal grain boundary of the magnetic layer from the underlayer is induced with post-annealing.    As a result, the magnetic layer has a structure that Cr exists only at the area near the crystal grain boundary and thereby non-magnetization of grain boundary region of magnetic layer can be realized.    Since the grain boundary region of magnetic layer is non-magnetized, magnetic mutual operation among the grains can be reduced and noise of magnetic recording medium can also be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional view of a disc medium of the present invention.

Fig. 2 is a diagram showing a crystal structure of a magnetic layer after the post-annealing.

Fig. 3 is a graph showing relationship between the post-annealing temperature and magnetization characteristic.

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Fig. 4 is a diagram showing the growth process of magnetic grains.

Figs. 5(a) and 5(b) are graphs showing the relationships between concentrations of additives of Co-based alloy and Ku values.

Fig. 6 is a graph showing the relationship between Cr concentration in CoCrPt and Ku value.

Fig. 7 is a graph showing the relationship between W concentration in CoW and Ku value.

Fig. 8 is a plan view of the magnetic disc drive as the embodiment of the present invention.

Fig. 9 is a cross-sectional view of the magnetic disc drive of Fig. 8 as the embodiment of the present invention.

Fig. 10 is a diagram showing a structure of a sputtering apparatus.

Fig. 11 is a flowchart of the process to form a medium in the embodiment of the present invention.

Fig. 12 is a cross-sectional view of an existing medium.

Fig. 13 is a flowchart of the process to form an existing medium.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 is a cross-sectional view of a magnetic recording medium of the present invention. In the magnetic recording medium 1 of the present invention, an underlayer 3, a magnetic layer 4, a protection layer

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5 are sequentially formed on a substrate 2. Each film forming the magnetic recording medium 1 will be explained below.

The substrate 2 is formed of a non-magnetic material of disc shape. A material forming the substrate 2 includes NiP plated aluminum (including aluminum alloy) disc, glass (including reinforced glass) disc, silicon disc having a surface oxide film, SiC disc, carbon disc, plastic disc, ceramic disc or the like. Moreover, the substrate 2 is not always required to have completed the texture process. A size of substrate 2 is determined depending on the kind of desired medium and magnetic disc drive as the application object or the like. In general, the external diameter is in the range of 65 mm to 95mm, the internal diameter is in the range of 20mm to 25mm and thickness is in the range of 0.635mm to 0.8mm.

The underlayer 3 is formed of a non-magnetic metal material mainly composed of chromium. As the practical material, a metal material mainly composed of only chromium or chromium alloy such as CrW, CrV, CrTI, CrMo or the like may be listed. The underlayer 3 is formed, for example, with the sputtering method such as the magnetron sputtering method or the like. As the adequate film forming conditions, for example, the substrate temperature is 30℃, Ar gas pressure is 3 to 5mTorr, input power is 100 to 800W. Moreover, it is

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also possible to introduce, in place of the sputtering method, the other film forming methods, for example, the vacuum evaporation method and ion beam sputtering method or the like. Film thickness of underlayer 3 is determined within a wider range depending on various factors but the thickness is preferentially set within the range of 2nm to 14nm to improve S/N ratio. If the underlayer film thickness is 2nm or less, a problem that sufficient magnetic characteristic cannot be obtained is generated and if thickness becomes 14nm or more, on the contrary, noise tends to be increased.

The magnetic layer 4 is formed of a Co-based alloy mainly composed of cobalt and an alloy where a non-magnetic material other than Cr is added to Co, for example, CoPt alloy and CoW alloy or the like are formed. It is preferable for the magnetic layer 4 that it is formed with the sputtering method such as the magnetron sputtering method or the like and for example, the substrate temperature is set to 30℃, as the adequate film forming conditions, Ar gas pressure is set to 3 to 5mTorr and input power is set to 100 to 800W. Moreover, the other film forming methods, such as vacuum evaporation method and ion beam sputtering method or the like may be used in place of the sputtering method.

The protection layer 5 is composed of a discrete carbon or a composite including carbon. For example, WC, SiC, B4C, carbon including hydrogen and a diamond

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like carbon (DLC) that is noted in such a point as having higher hardness may be listed. It is preferable for the protection layer 6 that it is formed with the sputtering method such as the magnetron sputtering method or the like. As the preferable film forming conditions, for example, the substrate temperature is set to 30℃, Ar gas pressure is set to 3 to 5mTorr and input power is set to 300 to 500W. Moreover, the other film forming methods such as vacuum evaporation method and ion beam sputtering method or the like can be substituted for the sputtering method. The thickness of the protection layer 6 is determined in a wider range depending on various factors and the preferable thickness is in the range of 4nm to 8nm.

Here, it is also allowed that a lubricant film is formed on the protection layer. The lubricant film is usually composed of a phlorocarbon resin based material in the thickness of 1nm to 2nm.

The present invention diffuses Cr included in the underlayer 3 into the crystal grain boundary of magnetic layer 4 with the post-annealing.

Fig. 2 shows a crystal structure in the magnetic layer 4 of the magnetic recording medium 1 after the post-annealing.

In Fig. 2, a dotted line indicates the grain boundary, the region surrounded by a solid line is the region composed of a Co-based alloy (Cr is not included)

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and the region surrounded by the dotted line and solid line is the region composed of a CoCr based alloy. From Fig. 2, it is understood that Cr is segregated only to the area near the crystal grain boundary with the post-annealing. Since Cr is diffused into the crystal gain boundary of the magnetic layer 4, magnetic mutual operation among the crystal grains of magnetic layer 4 is impeded. Thereby, generation of noise in the magnetic layer 4 can be controlled.

However, when the post-annealing is executed after formation of the protection layer 5 mainly composed of carbon as explained above, carbon reaches the surface of the underlayer 3 passing through the crystal grain boundary to form a film to impede diffusion to the grain boundary of magnetic layer 4 of Cr of the underlayer 3. Therefore, it is preferable to execute the post-annealing after the magnetic layer 4 is formed and before the protection layer 5 is formed. Moreover, the magnetic layer 4 is exposed before the protection layer 5 is formed and when the substrate 2 is exposed to the atmospheric condition under this condition, an oxide film is formed at the surface. Since this oxide film is condensed during the post-annealing to provide roughness of the surface, it is preferable that the post-annealing is conducted while the vacuum condition is maintained after lamination of the magnetic film 4.

Fig. 3 shows the temperature dependence

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characteristics of a coercive force Hc in the post-annealed medium (underlayer is Cr and magnetic layer is CoPt) and the standardized coercive force Hc/Hk.

As shown in Fig. 3, diffusion of Cr to the crystal grain boundary of magnetic layer from the underlayer is induced at the temperature higher than 350°C. Moreover, it is also understood that Hc/Hk value can be increased, while the anisotropic magnetic field Hk does not change, by setting the post-annealing temperature to 350°C or higher. These results indicate that the mutual operations among grains are reduced and diffusion of Cr to the crystal grain boundary of magnetic layer is accelerated. In the post-annealing temperature region exceeding 30°C, Hc/Hk value becomes higher as the post-annealing temperature rises. Therefore, it can also be proved that segregation of Cr can be controlled depending on the post-annealing temperature.

Fig. 4 shows a growth process of magnetic grains of magnetic layer. As the magnetic layer, CoCrPt is used and as the underlayer, Cr is used.

For acceleration of segregation of Cr due to the post-annealing, it is effective to introduce a medium forming technique to laminate the underlayer and magnetic layer with the sputtering method in place of the heat treatment of substrate. In this technique, as shown in Fig. 4, since the forming condition in which

one magnetic grain grows on one crystal grain of the underlayer is realized, the plain size of magnetic grains can be controlled with the plain size of crystal grain of the underlayer.

Figs. 5(a) and 5(b) show the graphs indicating the relationship between concentration of additives and anisotropic constant Ku in the Co based magnetic material. Fig. 5(a) is the graph where Pt is added as the additive, while Fig. 5(b) is the graph where Cr is added as the additive. From Fig. 5(a) and 5(b), it can be understood that when concentration of additive becomes higher, Ku becomes lower than 4e + 6(erg/cc) which is the Ku value of discrete element of Co. However, a lowering degree in the case where Cr is added as the additive becomes larger than that in the case where Pt is added and a higher reduction degree is indicated in the region where Cr concentration is 5at% or less. Therefore, if the CoCr based alloy is used for the magnetic layer, it is preferable to set Cr concentration to 5at% or less, if possible, to 3at% or less where the Ku value which is higher than the half of Ku value of discrete element of Co can be obtained.

Fig. 6 is a graph indicating the relationship the Cr to Pt ratio in CoCrPt (concentration of Co has the constant value of 78%) and Ku value. From Fig. 6, it can be understood that the Ku value is lowered when a rate of Pt is decreased and a rate of Cr is increased.

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When the rate of Pt is 0 and additional coefficient of Cr is 22% which is the practical adding coefficient, Ku becomes 4e + 5(erg/cc) which is about 1/10 of the Ku value of discrete element of Co.

Fig. 7 is a graph showing the relationship between adding coefficient of W in CoW and the Ku value. From Fig. 7, it can be understood while the adding coefficient of W is in the range of 0 to 16at% that when the adding coefficient of W is higher, the value of Ku becomes larger but when the adding coefficient of W exceeds 16at%, the Ku value is rapidly decreased. However, in CoCr, a Ku value higher than that in addition of Cr in the same concentration can be obtained. From Fig. 7, it can be said preferable that concentration of W should be 16at% or less when CoW is used for the magnetic layer.

As explained above, from the graphs of Fig. 5 to Fig. 7, it can be understood that addition of Cr remarkably reduces the Ku value and reduction of Ku value can be reduced or increased by adding Pt and W in place of Cr. When the discrete element of Co is used as the magnetic layer, a higher Ku value can be obtained as shown in Figs. 5(a) and 5(b) but simultaneously corrosion proof characteristic is deteriorated. Accordingly, it is required to enhance passivation but it is inferior for practical use. Moreover, when the magnetic material not including Cr is used, a problem is generated in which the grain boundary region cannot be

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non-magnetized. But, this problem can be solved by inducing diffusion of Cr into the crystal grain boundary of magnetic layer from the underlayer with the post-annealing explained above.

On the other hand, the present invention is also applied to the magnetic disc drive including the magnetic recording medium explained above and an example of the magnetic disc drive is shown in Fig. 8 and Fig. 9. Fig. 8 is a plan view of the magnetic disc drive of the present invention under the condition that a cover is removed, while Fig. 9 is a cross-sectional view along the line A-A of Fig. 8.

In these figures, numeral 50 designates a magnetic disc driven with a spindle motor 52 provided on a base plate 51. In this embodiment, three magnetic discs are provided.

Numeral 53 is an actuator supported to rotate on the base plate 51. One end of the actuator 53 is provided with a plurality of head arms 54 extending in the direction parallel to the recording surface of the magnetic disc 50. One end of the head arm is provided with a spring arm. A slider 40 is mounted to the flexure part of spring arm 55 via an insulation film not shown. The other end of actuator 53 is provided with a coil 57.

On the base plate 51, a magnetic circuit 58 formed of a permanent magnet and a yoke is provided and the

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coil 57 explained above is allocated within a magnetic gap of the magnetic circuit 58. A voice coil motor (VCM) is structured with the magnetic circuit 48 and coil 57. Moreover, the upper part of base plate 51 is covered with a cover 59.

Operations of the magnetic disc drive explained above will then be explained. While the magnetic disc 50 does not rotate, the slider 40 is in the stationary condition in contact with the saving zone of the magnetic disc 50. Next, when the magnetic disc drive 50 is rotated with the spindle motor 52, the slider 40 is levitated from the disc surface keeping a small gap with the air flow generated with rotation of the magnetic disc 50. When a current flows into the coil 57 while the slider is levitated, a propulsive force is generated in the coil 57 to rotate the actuator 53. The slider 40 moves to the position on the predetermined track of the magnetic disc 50 to read or write data from or to the disc.

In the present invention, a DC magnetron sputtering apparatus 10 as shown in Fig. 10 is used to form the predetermined film on the substrate. The sputtering apparatus 20 is provided, as shown in the figure, with a gas supply port 22 for guiding the gas into the sputtering chamber 21, an exhaust port 23, a susceptor 24 for supporting a disc substrate, a target 25 and a magnet 26.

In view of verifying the effect of use of the

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magnetic layer not including Cr and the effect of
non-heating of the substrate in the laminating process,
three kinds of media indicated below are manufactured
on trial to measure the respective magnetic
characteristics.

1.    Medium A:

    As shown in Fig. 1, the cross-section of the medium
A is formed of an underlayer 3, a magnetic layer 4 and
a protection layer 5 laminated sequentially on a
substrate 2.    The manufacturing process of medium A is
shown in Fig. 11.    The manufacturing process of medium
A will be explained with reference to Fig. 11.

S1:    An underlayer 3 is laminated n a substrate 2
consisting of a Si disc in the external diameter of 6.5mm,
internal diameter of 20mm and thickness of 0.635mm on
which surface a silicon oxide film is formed in the
thickness of 300nm.    The underlayer 3 is composed of
polycrystalline film of Cr.    After the chamber of the
sputtering apparatus is evacuated to 5e-10Torr, a film
is formed in the thickness of 5nm on the substrate 2
under the condition that the Ar gas pressure in the
sputtering chamber is set to 3mTorr.

S2:    A magnetic layer 4 is laminated on the underlayer
3.    The magnetic layer 4 is formed of CoPt alloy
polycrystalline film and this film is formed in the
thickness of 14nm on the underlayer 3 under the conditions
that the Ar gas pressure in the sputtering chamber is

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set to 3mTorr and input power is set to 100W. The magnetic layer 4 of medium A has the composition of cobalt of 88at% and platinum of 12at%.

On the occasion of forming a film of magnetic layer 4, a bias voltage is set to 0V in order to avoid the heat processing of the substrate. Moreover, in order to attain high purity of film, a partial pressure of oxidized gas element is reduced to 1e-11Torr or less by reducing the vacuum base pressure (1e-9Torr) and purifying the Ar gas.

S3: After the magnetic layer 4 is formed, the vacuum condition is held and the post-annealing is performed for 20 seconds at 450℃ to sufficiently induce the diffusion of Cr to the magnetic layer 4 from the underlayer 3.

S5: A protection layer 5 is laminated on the magnetic layer 4. The protection layer 5 is formed after the post-annealing. This layer 5 is formed in the thickness of 5nm on the magnetic layer 4 under the conditions that substrate temperature is 30℃, Ar gas pressure in the sputtering chamber is set to 3mTorr and input power is set to 1000W.

From the medium A manufactured as explained above, a value of Ku of 3.7e+6 (erg/cc) and a value of Hc/Hk of 0.44 have been obtained. The Ku value obtained here is larger than 8e+5 (erg/cc) which is the value of Ku of the medium of which magnetic layer is composed of

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Co66Cr22Pt12. Moreover, as the value of Hc/Hk, 0.44 has been obtained by reflecting the width of the non-magnetized region of the grain boundary portion formed with diffusion of Cr into the grain boundary of magnetic layer. From this result, it has been proved that sufficient grain boundary segregation of Cr can be realized even in the medium where Cr is not added to the magnetic layer. Here, it has also been confirmed that Cr exists only in the region within 3nm from the crystal grain boundary in the magnetic layer 4.

2. Medium B:

A structure of the layer of medium B is shown in Fig. 12. Unlike the medium A, the medium B has a magnetic layer 4' including Cr. The manufacturing process of medium B is shown in Fig. 13. The manufacturing process of medium B will be explained with reference to Fig. 13.

S11: An underlayer 3 is laminated on a substrate 2. Shape and material of the substrate 2 are identical to that of the medium A. The underlayer 3 is composed of the polycrystalline film of Cr and it is formed in the thickness of 5nm on the substrate under the conditions that the sputtering chamber is evacuated to 5e-Torr, the Ar gas pressure in the sputtering chamber is set to 3mTorr and input power is set to 100W.

S12: The substrate 2 is heated up to 250℃.

S13: A magnetic layer 4 is formed on the underlayer 3.

The magnetic layer 4' is composed of the CoCr group alloy magnetic material and it is formed on the underlayer 3 in the thickness of 14nm under the condition that the substrate 2 is heated, the Ar gas pressure in the sputtering chamber is set to 3mTorr and input power is set to 100W. The composition of magnetic layer 4' of medium A has the composition of cobalt of 75at% and chromium of 13at%.

S14: A protection layer 5 is also formed on the magnetic layer 4'. The protection layer 5 is formed in the thickness of 5nm on the magnetic layer 4' under the conditions that the substrate temperature is set to 30℃, the Ar gas pressure in the sputtering chamber is set to 3mTorr and input power is set to 1kW.

In the medium B manufactured as explained above, since Cr is added to the magnetic layer 4', the Hc/Hk value of 0.3 has been obtained because the grain boundary region can be non-magnetized by segregating Cr included in the magnetic grains into the grain boundary on the occasion of deposition. However, the Ku value obtained has only been 7e+6(erg/cc).

3. Medium C:

Shape of cross-section of the medium C is identical to that of medium A and is shown in Fig. 1. Moreover, the manufacturing process is as shown in Fig. 11 which is identical to the process of medium A. Only difference from the manufacturing process of medium A is that a

substrate is heated up to 250°C when the magnetic film 4 is formed with the sputtering method.

From the medium C manufactured as explained above, the Ku value of 3.7e+6 (erg/cc) has been obtained as in the case of medium A.  However, diffusion of Cr into the grain boundary of magnetic layer does not occur and the Hc/Hk value has been reduced to 0.1 or less.

From the values of Ku and Hc/Hk of each medium manufactured as explained above, it can be understood that a comparatively larger Ku value can be obtained in the media A and C where Cr is not added to the magnetic layer and moreover a large Hc/Hk value has been obtained in the medium A where the substrate is not heated when the magnetic layer is formed.  From this result, it has also been confirmed that Cr should not be added to the magnetic layer to obtain a large Ku value, while the sputtering process should be conducted without heating the substrate in order to obtain a large Hc/Hk value.

Industrial Applicability of Utilization

In the present invention, since the Co based alloy in which Cr is not added is used as a material of magnetic layer, Ku value maintains a higher value.  Since the Ku value is high, the volume of crystal grains for starting deterioration of magnetic characteristic due to the thermal disturbance becomes small and thereby reduction in thickness of the magnetic film can be accelerated.  As a result, an area of one bit can be

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reduced, and thereby high recording density can be achieved. Moreover, since the Cr-based alloy is used as the material of underlayer, Cr can be diffused into the grain boundary of magnetic layer from the underlayer. Since Cr is diffused into the grain boundary, the grain boundary of the magnetic layer can be non-magnetized. As a result, the magnetic mutual operation among grains can be controlled and noise of magnetic recording medium can also be reduced.

As explained above, in the present invention, reduction in thickness of magnetic layer and noise can be accelerated and thereby high recording density of magnetic recording medium can be realized.